Data Variability and the Use of Chironomids In Environmental Studies: The Standard Error of the Midge

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Abstract
Many aquatic insect taxa have been used as indicators of environmental quality. However, none has been used as extensively as chironomids (Diptera: Chironomidae). The successful use of midges in environmental studies relies on the integrity and reliability of chironomid databases with species-specific environmental requirements. Errors or inconsistencies within these databases may lead to inconclusive or erroneous results. Much of this can be attributed to methodological errors associated with using midges in environmental assessment. These include: 1) failure to identify to species, 2) inaccurate identifications, 3) inappropriate sampling designs, and 4) inadequate sampling, sorting and sample preparation techniques. These errors can have substantial impacts on estimates of species richness and diversity, on the detection of environmental impact and change, and on determinations of secondary production rates and energy flow in aquatic ecosystems. We refer to the common tendency to ignore or misuse chironomids in environmental assessment as "The Standard Error of the Midge."

Key Words: midges, sampling, taxonomy, data variability, environmental assessment

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Introduction

Aquatic insects long have been used as indicators of water quality (Hellenthal 1982). Fundamental to assessing environmental quality in aquatic habitats is the recognition of reliable indicator species or, preferably, indicator associations or assemblages. Historically, one of the most widely used groups of indicator organisms in both lotic and lentic ecosystems has been larvae of the dipteran family Chironomidae, or midges.

In lentic ecosystems, Thienemann (1922) used genera of chironomids, primarily Chironomus and Tanytarsus, as the basis for his lake typology system. In lotic systems, some of the earliest pollution studies recognized the usefulness of chironomids as indicators of impacted areas (Gaufin and Tarzwell 1952, Richardson 1921).

The reasons that chironomids have been used extensively in assessing water quality are sound. The family Chironomidae is a species-rich group with about 15,000 species worldwide and 1000-2000 species in North America (Coffman and Ferrington 1984). Midges are ubiquitous and frequently the numerically dominant insects in aquatic habitats, attaining densities in excess of 50,000 m^{-2} (Coffman and Ferrington 1984). Finally, the environmental requirements of many chironomid species are environmentally specific and well documented (Beck 1977, Dawson and Hellenthal 1986).

Unfortunately, these characteristics, which give chironomids such great potential in environmental assessment, also contribute to serious difficulties for environmental biologists. Because of their small size (mature larvae range from 2-30 mm) and because of their high densities, the collecting and sorting of larval chironomids is a tedious and time-consuming process. In addition, accurate species-level identifications of larval chironomids may be difficult for the untrained biologist. It is these species identifications, however, that are essential for effective use of chironomids to assess environmental quality. When combined, errors associated with the sampling and identifi-

cation of chironomids result in highly variable and unreliable data.

Study Site

The data used to illustrate the common errors associated with using chironomids were collected from Juday Creek, a third-order stream in northern Indiana (41°43'N, 86°16'W, elevation = 206 m). Juday Creek is a tributary of the St. Joseph River that flows north into Lake Michigan. Mean annual discharge in Juday Creek is 0.26 m^3s^{-1} with a range of 0.09 m^3s^{-1} in August to 0.56 m^3s^{-1} in April (Schwenneker 1985). The study site was located 0.35 km upstream from the confluence in a natural woodland maintained by the Izaak Walton League of America. This section of stream has a moderate gradient of 1.3% and is primarily riffle habitat with occasional small pools and a pool:riffle ratio (Platts et al. 1983) of 0.1:1.

Results and Discussion

Sampling

One of the greatest sources of variability in using chironomids, particularly in stream studies, is the design of a sampling regime. Sampling must consider both spatial and temporal population characteristics. As with most stream insects, the distribution of chironomid larvae within a stream reach typically is heterogeneous. This heterogeneity must be considered in the design of sampling programs that attempt to detect changes in community structure or population densities. To minimize variability, researchers may have to choose between collecting many samples from a wide range of microhabitats or collecting fewer samples that are restricted to a particular microhabitat.

The distribution of chironomids, even within a single riffle area, is highly variable (Figure 1). Thus, studies that restrict sampling to a particular area of the stream, such as the center, still can result in highly variable density estimates. This variability, however, can be minimized

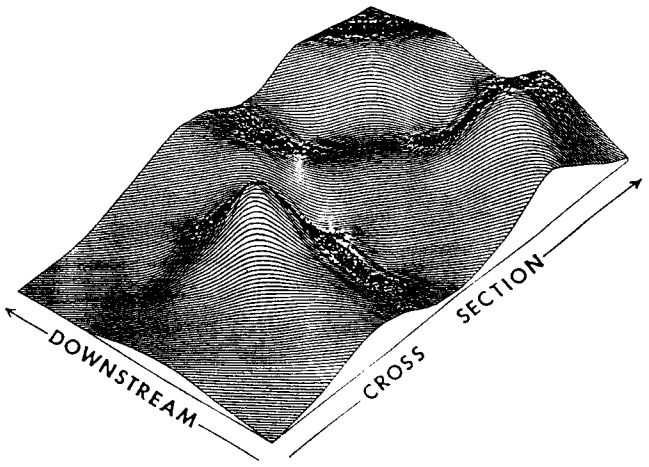

Figure 1. Three-dimensional response surface showing the distribution of the chironomid Pagastia (Oliver) (Diamesinae) during the winter within a single riffle area of Juday Creek.

by conducting a preliminary study to determine species-specific microdistributional patterns (Schwenneker and Hellenthal 1984). Results from this preliminary study then can be used to develop a more efficient sampling strategy designed to address the specific question being considered. For example, prior to conducting a study in Juday Creek, preliminary sampling was used in an attempt to minimize variability of chironomid density estimates. Based on results from this preliminary study, a sampling program was designed that resulted in density estimates with standard errors within 5% of the mean.

In addition to considering spatial variability in designing adequate sampling programs, temporal variability components also must be addressed. Since the Chironomidae is a diverse taxonomic family, often with more than 100 species found in a given habitat (Boerger 1981), a wide variety of life cycles commonly are represented. These can range from univoltine to asynchronous. Species with overlapping cohorts may make determination of life cycles difficult. Chironomid life cycles of three, four

or more generations per year are common. As a result of these diverse life cycles, densities of chironomids can vary dramatically throughout the year (Figure 2). Densities of chironomids in Juday Creek range from 7500 m^{-2} in October to 90,000 m^{-2} in early May. Variations such as these must be taken into account in the design of adequate sampling programs. In Juday Creek, 50 samples would be required to detect a 100% change in total chironomid numbers during the summer while only 15 samples would be necessary during the winter. It is clear that a knowledge of species life histories is essential to design the most cost-effective and efficient sampling program. Knowledge of life histories also is essential to ensure that failure to collect a particular species is not misinterpreted as an effect of an environmental impact.

Instar-specific distributional patterns also may be an important source of data variability. The summer and winter distributions of Parametriocnemus lundbecki (Johannsen) (Orthocladiinae), in addition to showing substantial spatial heterogeneity within each season, also demonstrate large interseasonal distribution differences (Figure 3). These differences are primarily the result of early instar larvae predominating along stream margins in the summer and moving toward the center of the stream as they mature during winter. The summer sample was collected early in the season at a time when most of the organisms were second instars. The winter sample, on the other hand, had a mixed assemblage of second, third and fourth instars. The high degree of intra-annual variability due to instar-specific and species-specific distributional patterns may limit the ability to detect significant changes in chironomid densities and species composition during the course of a year. This variability can be minimized by restricting sampling to a particular time of year. This decision should be based on the specific question being addressed. For example, in studies that attempt to detect changes in chironomid densities, sampling should be conducted at times when densities are most stable. Such an approach will result in a greater likelihood of detecting an environmental impact in addition to saving substantial time, manpower and money. Thus, failure to consider both spatial and temporal aspects of chironomid sampling can result in the inability to detect environmental change or an erroneous conclusion that an environmental change has occurred.

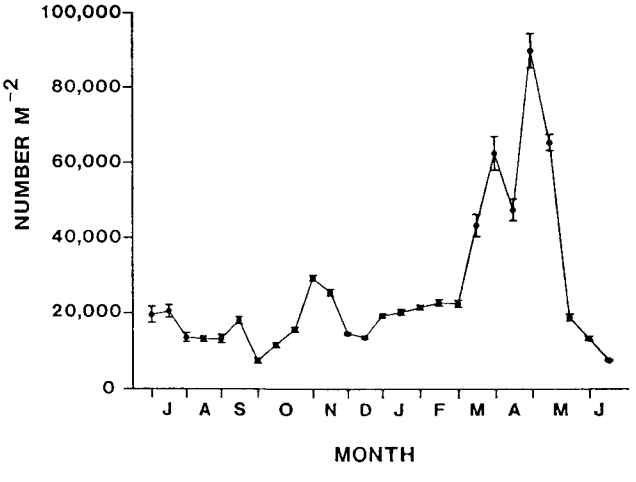

Figure 2. Annual variability in total larval chironomid density (mean density m^{-2} ± 95% CI) in Juday Creek.

A second major source of variability is choice of sampling method. Hess and Surber samplers, which are among the most commonly used benthic samplers, typically have too coarse mesh sizes to retain most larval chironomids. The use of one of these samplers or a similar type of net, such as a kick-net, leads inevitably to the loss of many chironomids and, therefore, to a gross underestimation of chironomid densities. In addition, methods such as these also bias sampling in favor of larger taxa and may lead to serious underestimates of species richness and

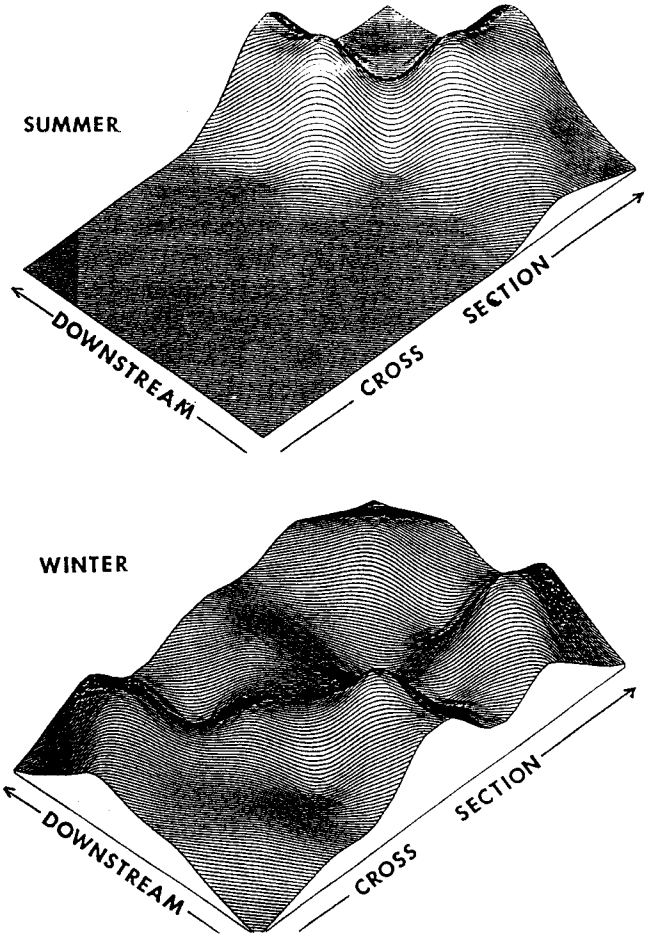

Figure 3. Three-dimensional response surface illustrating interseasonal variability in microdistributional patterns of the chironomid Parametriocnemus lundbecki (Johannsen) (Orthocladiinae) in Juday Creek.

diversity. Similar errors occur when sampling involves scrubbing rocks, tiles or other substrates with brushes. Passing benthic samples through one or more sieves to facilitate sample processing and sorting also may cause the loss of substantial numbers of chironomids. In Juday Creek, even the use of a 250μm mesh sieve often resulted in the loss of as much as 80% of the larval chironomids. Samples with high densities should be subsampled repeatedly until a manageable density is attained. Analyses should then be conducted on the entire subsample.

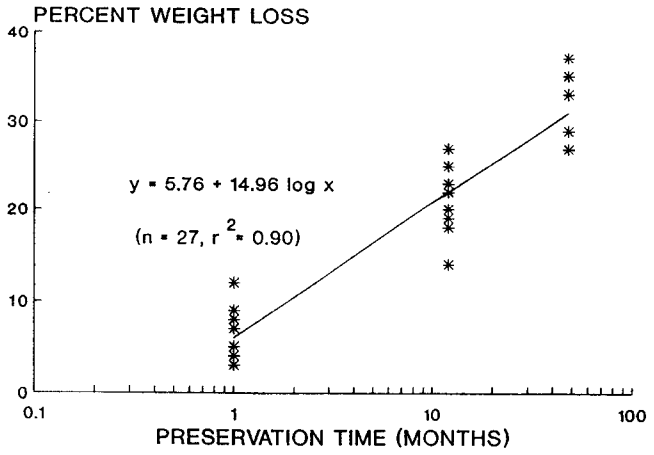

Figure 4. Replicated linear regression of percent weight loss of chironomid larvae versus length of time in an 80% ethanol preservative.

Sampling errors also occur in attempts to measure standing stock biomass of chironomids, such as those in secondary production studies. Conflicting views can be found in the literature as to the effects of preservatives on biomass estimates. Some researchers have reported little or no weight loss upon preservation in formalin or ethanol (Wiederholm and Eriksson 1977) while others claim substantial losses in weight (Howmiller 1972). In a four-year study of the effects of an 80% ethanol preservative on dry mass of larval chironomids, we found that chironomid biomass decreased by 5% after the first month, 22% after 1 year (i.e. an additional 17% from month 1 to month 12) and 31% after 3 years (or an additional 9% from month 12 to month 48) (Figure 4). Percent weight loss was described by the linear regression:
$y = 5.76 + 14.96 \log x$ ($n=27$, $r^2=0.90$), where x = months in preservative. Weight loss using other types of preservatives also may occur. Thus,

the length of time in preservative can result in substantial differences in chironomid standing stocks observed between different studies as well as within a study. Understanding the relationship between duration in preservative and changes in biomass is essential in any study that relies on estimates of standing stocks or secondary production. The duration of these studies should correspond to the maximum length of time any one sample remains in preservative prior to biomass determination.

It is now clear that different methods can yield substantially different, and potentially conflicting, results. Thus, the high level of variability observed among studies using chironomids is not surprising given that results from studies using different methods often are compared.

Identification

Another major source of error in environmental studies using chironomids concerns larval identifications. Taxonomic keys for larval chironomids are based largely on conspicuous, or not so conspicuous, headcapsule characteristics of mature fourth instar larvae. To see these characters, it is necessary to sever the headcapsule and mount both headcapsule and body on a microscope slide. Thus, the identification of even a few larvae is an extremely time-intensive ordeal. It is not difficult to understand why many researchers have tried to find short cuts to avoid this whole procedure. The most common short cut is to group all chironomids at the family level and to deal with the midges as a single taxonomic entity. This approach invariably will result in the loss or obscuring of important information such as species diversity and species richness that could be used in assessing environmental quality. This is probably why the use of chironomids as environmental indicators has had varying success. If expertise in the identification of larval chironomids is lacking, it is essential to seek additional assistance so that the sensitivity of the results can be maximized.

Ideally, the identification of chironomids to the species level would be of greatest value since published environmental requirements are described for individual species. However in the case of some larval chironomids, the inability to make species-level identifications without rearing the larvae, combined with the high number of species collected in a given habitat, result in studies identifying chironomids to a taxonomic level higher than species, such as species group or subfamily. This approach obscures important ecological information since a high level of diversity exists within these groups with respect to species-specific environmental requirements. The different taxonomic levels to which midges are identified in different studies must be kept in mind. Failing to do so can result in the inability to assess the usefulness of chironomids in environmental evaluation.

An obvious source of error when using chironomids is the accuracy of the identification. Chironomid taxonomy has gone through major changes in the past decade and continues to change at a rapid pace. Relying on outdated handbooks that provide keys to midges can result in costly misinterpretations of community composition. These misinterpretations are perpetuated in the literature and inevitably result in erroneous or conflicting conclusions that cast doubt on the usefulness of midges in environmental research. The value of accurate and complete chironomid identifications can not be overstated. Confirmation of species identifications by qualified researchers and the maintenance of voucher collections are important steps to ensure the integrity of chironomid databases.

Given all of the variability associated with using chironomids and the

Table 1. Assumptions of the size-frequency method and effects on secondary production estimates if assumptions are violated.

Assumption	Effect on Production Estimate
All species have similar life cycles	Underestimate
All species attain same maximum size	Overestimate
Same length of time is spent in each size class	Overestimate or Underestimate

difficulty in working with them, the question that often arises is why do they even have to be considered? One way of assessing the importance of chironomids would be to examine their role in energy transfer and their contribution to overall stream insect secondary production. Previous studies that have attempted to examine chironomid secondary production have committed many of the same errors discussed above.

One of the most commonly used methods to calculate chironomid secondary production is the size-frequency method (Hynes and Coleman 1968). Since this method does not necessitate cohort separation, chironomids usually are pooled at the family level and production is calculated on the family as a whole. However, a series of assumptions associated with this method is invariably violated when chironomids are grouped into a single taxonomic group. These assumptions are: 1) all species have similar life cycles, 2) all species attain the same maximum size, and 3) the same length of time is spent in each size class. Violating these assumptions can either underestimate or overestimate secondary production or can have unpredictable effects on secondary production estimates (Table 1).

In a study conducted in Juday Creek, we estimated chironomid secondary production by following 48 species for one year and calculating secondary production on a species-specific and, usually, a cohort-specific basis without grouping midges at some higher taxonomic level. We found that the 15 numerically dominant chironomid species accounted for over 80% of the total stream insect secondary production (Figure 5). Thus, chironomids are an important energetic component in streams and must be considered in any rapid bioassessment or other environmental assessment program.

Conclusions

The effects of common methodological and taxonomic errors in chironomid studies have strong implications in many areas of aquatic ecology such as designing adequate sampling programs, the examinations of secondary production and seasonal patterns of energy flow, and the evaluation of stream diversity, as well as the ability to conduct successful environmental monitoring. If chironomids are to be used successfully in future environmental studies, reducing the level of non-impact related variability is crucial. This can be achieved best by reducing what we have called the "standard error of the midge."

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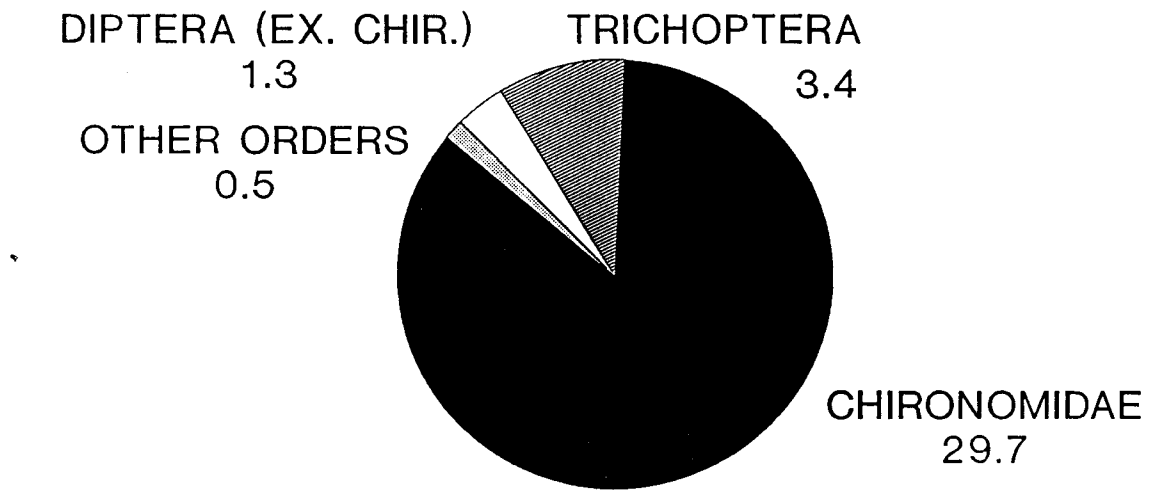

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